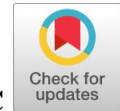


# Electrochemical Behavior of Plasma-Sprayed Stainless Steel

Anushraj B, Winowlin Jappes J T, Adam Khan M, Dillibabu V and Brintha N C



**Abstract:** The effect of electrochemical behavior of plasma sprayed NiCr–Cr<sub>2</sub>O<sub>3</sub> (80:20) and Al<sub>2</sub>O<sub>3</sub>– 40% TiO<sub>2</sub> as coating on stainless steel 316L were investigated. The polarization studies were carried out in 1.0M H<sub>2</sub>SO<sub>4</sub> and 3.5% NaCl solution as a corrosive medium. The corrosion potential is more positive in the coated sample and gives good corrosion resistance when compared to bare sample. The surface characterization studies were carried out through electron microscope attached with energy dispersive spectroscopy. It was found that intergranular attack and pitting corrosion takes place in the sample exposed in 1.0M H<sub>2</sub>SO<sub>4</sub> and large crater was found in the sample exposed in 3.5% NaCl solution.

**Keywords :** Corrosion, Coating, polarization

## I. INTRODUCTION

Stainless steel found wide application in medical and surgical equipments, chemical industry, paramedical and food industry. There are several types of stainless steel they are austenitic stainless steels, ferritic stainless steels, duplex and super duplex stainless steels. Yin et.al [1] evaluated that the ferritic and martensitic steels when exposed to 600°C corrosion rate was high. Also in the grain boundaries oxide film was formed and minor cracks are formed on the surface of the sample. Zhang et.al [2] reported that nodular corrosion takes place in the stainless steel (SS316L) in super critical water. Xu et.al [3] investigated the corrosion behavior of stainless steel in super critical water and founds that corrosion rate is increased with the increase in temperature and coefficient of oxidation.

Thermal spraying coating produces the spalling of splats due to their low bonding of the substrate [4, 5]. High velocity oxygen fuel (HVOF) spraying improves the porosity of the coating [6]. The remelting of substrate improves the

corrosion resistance of the substrate when it is exposed in corrosive medium [7]. The oxides and metallic coatings of the substrate define the mechanical and chemical properties of the uncoated sample [8]. The oxides such as ZrO<sub>2</sub>, Cr<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, etc are source materials used as surface coating [9, 10]. The plasma spray coating is best suited for thermal barrier coating materials [11].

Mahesh et al [12] investigated the hot corrosion behaviour of NiCrAl coating deposited on Ni- and Fe-based superalloy substrates by using HVOF process in molten salt environment (Na<sub>2</sub>SO<sub>4</sub>-60% V<sub>2</sub>O<sub>5</sub>) at 900°C under cyclic conditions. The mass gain measurements were also performed after each cycle to establish the kinetics of corrosion using thermogravimetric technique. The results showed that the bare superalloys experienced higher weight gain. The NiCrAl-coated Superni 750 alloy (SN 750) provided a better protection among the coated superalloys. The formation of oxides and spinels of nickel, chromium and aluminum believed to have contributed for better resistance to hot corrosion.

In this investigation, the stainless steel of 316L is coated with NiCr–Cr<sub>2</sub>O<sub>3</sub> (80:20) and Al<sub>2</sub>O<sub>3</sub>– 40% TiO<sub>2</sub> by plasma spray coating. The coated samples and uncoated samples are exposed to 1.0M H<sub>2</sub>SO<sub>4</sub> and 3.5% NaCl solution to evaluate the corrosion resistance of the substrate.

## II. EXPERIMENTAL SETUP

The chemical composition of stainless steel used in this experimental investigation is listed in table I. The samples are coated with plasma coating with having NiCr–Cr<sub>2</sub>O<sub>3</sub> (80:20) and Al<sub>2</sub>O<sub>3</sub>– 40% TiO<sub>2</sub> as a feed stock material. The parameters used for coating is listed in table II. The coating was carried out at room temperature. The thickness of the coating varies from 250-300 micron. The electro chemical behavior of stainless steel with and without coating was carried out in 1.0M H<sub>2</sub>SO<sub>4</sub> and 3.5% NaCl Solution.

Table I: Chemical Composition of Stainless Steel

Element	Ni	Cr	Mo	S	Si	Mn	C	P	Fe
Weight %	12	17	2.5	0.03	1	2	0.08	0.045	bal

Potentiostat is used to measure electrochemical polarization. It consists of three electrodes which is arranged with the sample as a working electrode, platinum electrode as counter electrode and calomel electrode as the reference electrode. The measurement procedure is adopted as per ASTM G3-14 standard. The exposure area is 1 cm<sup>2</sup> in room temperature. The sample with and without coating is exposed in 3.5% NaCl solution and 1.0M H<sub>2</sub>SO<sub>4</sub> solution.

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The sweep voltage is set to -250 to 250 mV after the open circuits get stabilized at a sweep rate of 1mV/sec. The electrochemical polarization measurement is done through TAFEL plot. The electron microscope attached with energy dispersive spectroscopy is used to study the characterization of the exposed material.

**Table II: Parameters used for Atmospheric Plasma Coating**

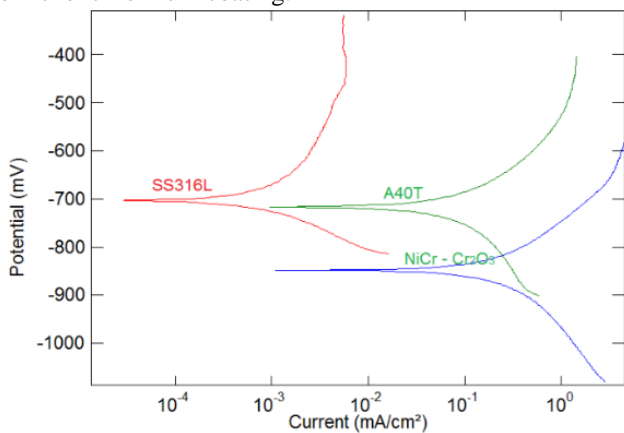
Spraying condition	Parameters	Units
Plasma Arc Current	450 – 500	A
Arc Voltage	60 – 70	V
Plasma Gas (Argon)	1.3 – 1.5	(x10-3) m <sup>3</sup> / s
Secondary Gas (Hydrogen)	0.3 – 0.4	(x10-3) m <sup>3</sup> / s
Powder feed rate	0.66 – 0.83	g / s
Torch to base distance	76 – 125	mm

**III. RESULTS AND DISCUSSION**

**A. Behavior of Corrosion in 1.0M H<sub>2</sub>SO<sub>4</sub>**

**1) Electrochemical Polarization Test**

The influence of with and without coated samples are subjected to electrochemical corrosion study. Figure 1 shows the polarization graph obtained for surface exposed in 1.0M H<sub>2</sub>SO<sub>4</sub>. From the graph it is confirmed that the bare stainless steel have high corrosion due to the current density is high. In the NiCr–Cr<sub>2</sub>O<sub>3</sub> the current density is low also when compared to bare sample corrosion potential is high. Nickel chromium coating in the stainless steel gives good corrosion resistance since these two elements is acts as corrosion barrier. The Al<sub>2</sub>O<sub>3</sub> coating also has better corrosion resistance when compared to bare sample and low corrosion resistance to nickel chromium coating.

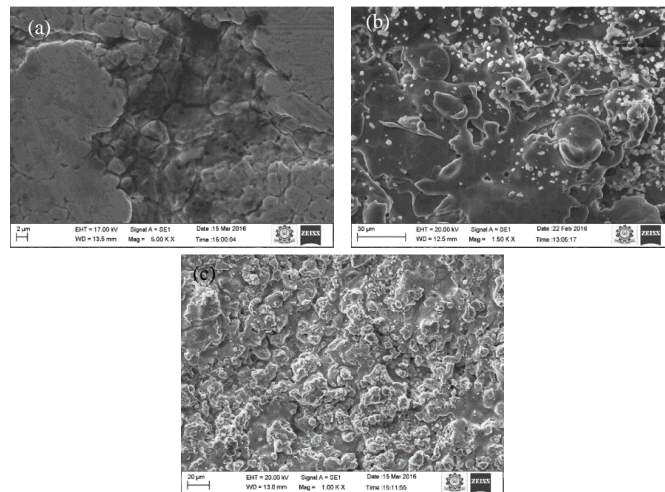


**Fig 1: Polarization graph obtained by the sample exposed to 1.0M H<sub>2</sub>SO<sub>4</sub>**

**2) Surface Analysis**

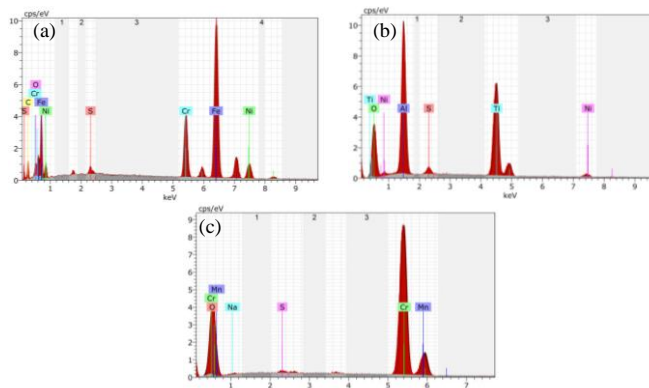
The coated and uncoated sample exposed to 1.0M H<sub>2</sub>SO<sub>4</sub> was subjected to surface analysis is shown in figure 2. The bare sample exposed in 1.0M H<sub>2</sub>SO<sub>4</sub> was found intergranular attack and pitting takes place. Due to both the corrosion mechanism takes place in the sample corrosion is high and it is clearly confirmed in the electrochemical analysis. The Al<sub>2</sub>O<sub>3</sub> coated samples descaling takes place on the sample and coating is act as barrier to corrosion. The NiCr–Cr<sub>2</sub>O<sub>3</sub> -coating is act as protective layer to improve the corrosion

resistance.



**Fig 2: SEM image of Sample exposed in 1.0M H<sub>2</sub>SO<sub>4</sub> Solution (a) Bare (b) Al<sub>2</sub>O<sub>3</sub> –TiO<sub>2</sub> (c) NiCr–Cr<sub>2</sub>O<sub>3</sub>**

Figure 3 shows the element distribution of sample exposed in 1.0M H<sub>2</sub>SO<sub>4</sub>. The segregation of iron element is more in the bare sample, Al<sub>2</sub>O<sub>3</sub> coated sample the segregation of aluminium is high and nickel chromium coated sample the segregation of chromium is high. From the element distribution it clearly confirmed that the chromium and aluminium is act as corrosion resistance element.



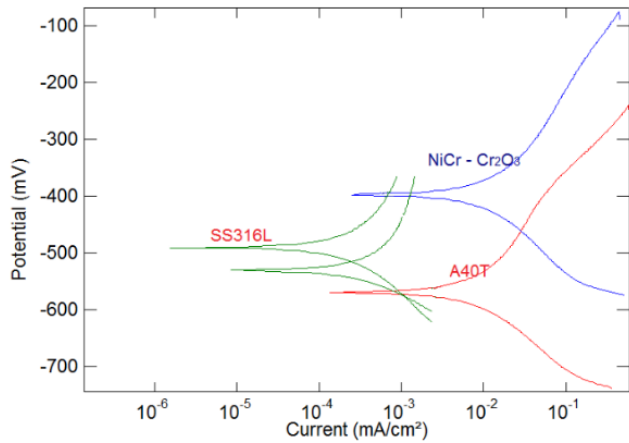
**Fig 3: Element Distribution of Sample Exposed in 1.0M H<sub>2</sub>SO<sub>4</sub> Solution (a) Bare (b) Al<sub>2</sub>O<sub>3</sub> –TiO<sub>2</sub> (c) NiCr–Cr<sub>2</sub>O<sub>3</sub>**

**B. Behavior of Corrosion in 3.5% NaCl solution**

**1) Electrochemical Polarization Test**

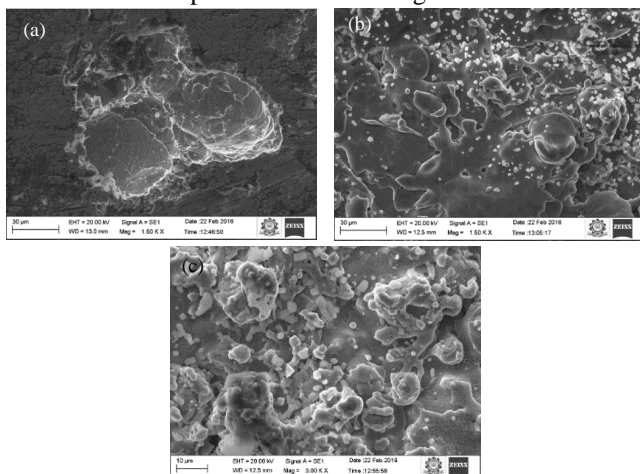
The Figure 4 infers the graph obtained from the electrochemical analysis of sample exposed in 3.5% NaCl solution. The nickel chromium coated sample has good corrosion when compare to bare sample and aluminum coated sample. The nickel coated sample has low current density and more positive corrosion potential due to the reason the corrosion resistance is increased. The bare sample has high current density whereas Al<sub>2</sub>O<sub>3</sub> coated sample has low current density. The Al<sub>2</sub>O<sub>3</sub> coated sample and bare sample has more negative corrosion potential when compared to nickel-chromium coated sample.



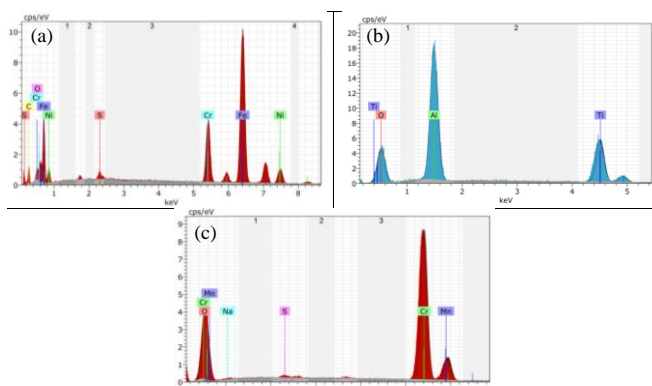


**Fig 4: Polarization graph obtained by the sample exposed to 3.5% NaCl**

Figure 5a shows the SEM image shows the bare sample exposed in 3.5% NaCl Solution. The sample exposed in 3.5% of NaCl solution the crater takes place in the surface. The SEM image aluminum oxide coated sample exposed in sodium chloride solution is shown in figure 5b. The oxides are formed on the surface of the sample. These oxides may act as a protective layer to the sample. The SEM image of nickel chromium coating the sodium salts are present on the surface of the sample is shown in the figure 5c.



**Fig 5: SEM image of Sample Exposed in 3.5% NaCl Solution (a) Bare (b) Al<sub>2</sub>O<sub>3</sub>-TiO<sub>2</sub> (c) NiCr-Cr<sub>2</sub>O<sub>3</sub>**



**Fig 6: Element Distribution of Sample Exposed in 3.5% NaCl Solution (a) Bare (b) Al<sub>2</sub>O<sub>3</sub>-TiO<sub>2</sub> (c) NiCr-Cr<sub>2</sub>O<sub>3</sub>**

The element distribution of sample exposed in 3.5% NaCl solution is shown in figure 6. The bare sample exposed in NaCl solution the segregation of iron element is high due to

this anodic dissolution is takes place. This anodic dissolution reduces the corrosion resistance of the sample. The aluminium coated sample aluminium oxide segregation is high which act as the corrosion resistance to the sample. The nickel chromium coated sample the element chromium and magnesium segregation is high which gives good corrosion resistance.

#### IV. CONCLUSIONS

In this work the electrochemical behavior of stainless steel with coating of Al<sub>2</sub>O<sub>3</sub>-TiO<sub>2</sub> and NiCr-Cr<sub>2</sub>O<sub>3</sub> exposed in 1.0M H<sub>2</sub>SO<sub>4</sub> and 3.5% NaCl solution were investigated. The conclusions are summarized as follows:

- The stainless steel 316L is corrosive resistance up to a thrust hold value. The bare metal has undergone grain boundaries attack and deteriorate fast in acidic medium.
- In NiCr - Cr<sub>2</sub>O<sub>3</sub> coated sample has observed with scaling of oxides with micro pores in both the corrosive medium. Alumina - titania coatings possess good surface resistance to acidic and alkalinity medium.
- The NiCr - Cr<sub>2</sub>O<sub>3</sub> coated sample gives good corrosion resistance when exposed in both the corrosive medium.

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